

PATENT SPECIFICATION

769.038



Date of Application and filing Complete Specification: Nov. 30, 1954.

No. 34686/54.

Application made in United States of America on Dec. 1, 1953.

Application made in United States of America on June 9, 1954.

Complete Specification Published: Feb. 27, 1957.

Index at acceptance:—Class 38(2), T1F, T7(A2B: A5: C1A: C4).

International Classification:—H02L.

COMPLETE SPECIFICATION

Improvements in or relating to Inductive Devices

- We, BENDIX AVIATION CORPORATION, a corporation of the State of Delaware, United States of America, of 1104 Fisher Building, Detroit, Michigan, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—
- The present invention relates to electrical apparatus having two relatively movable inductively coupled elements and more particularly to such apparatus for producing a non-sinusoidal relationship between the coupling or output voltage and the relative position of the two relatively movable elements. The present invention relates especially to variable conductors and rotatable transformers.
- Heretofore, rotatable transformers or variable inductive devices of the type known as synchros have been employed in telemetering and servomechanism applications. However, in prior synchro devices and rotatable transformers of conventional practical construction the relationship between coupling or output and the angular displacement between the rotor and stator elements follows a substantially sinusoidal law. Various constructions and winding distributions for obtaining a substantially pure sinusoidal relationship between coupling or output and displacement are disclosed in our patent specifications Nos. 671,632 and 680,503.
- However, there are many applications for variable inductive devices where it is required that there be a non-sinusoidal relationship between coupling and relative displacement or between output voltage and relative displacement. In one prior construction the windings of several ganged separate inductive devices were connected in series to produce a non-sinusoidal relationship between a resultant voltage and relative displacement between the primary and secondary windings.
- Recent developments in the telemetering, servomechanism and computer fields require a rotatable transformer or variable inductor with primary and secondary windings wherein there is a substantially linear relationship relating the degree of coupling or flux linkages between the primary and secondary windings to the relative displacement between the primary and secondary windings. Stated differently, in the case of a rotatable transformer having one secondary winding it is required for a given input or primary voltage that the relationship between the secondary voltage and the angular displacement between primary and secondary windings be substantially linear over a predetermined working range of angular displacements. One attempt to provide a rotatable transformer having such a linear relationship involved either arranging windings so that, starting with a certain number of turns at one end of one pole face, the number of turns were progressively increased toward the other end or else employing a variable gap and uniform windings. With such construction a concentrated secondary winding could be employed having a pitch which is a fraction of the pitch of the primary winding. However, such construction and winding arrangement proves impractical and unsatisfactory from the standpoint of accuracy and production requirements involving minimum expense.
- It is an object of the present invention to provide a variable inductive device, such as a rotatable transformer, in which one of the two inductively coupled elements has a winding so distributed that the relationship between coupling or output and the relative position or displacement between the two inductively coupled elements follows a predetermined desired non-sinusoidal law or characteristic.
- It is another object of the present invention to provide a variable inductive device, such as a rotatable transformer, in which one of the two inductively coupled elements has a winding so distributed that the relationship relating degree of coupling of flux linkages or secondary voltage to the angular displacement between the primary and secondary windings is substantially linear with a substantially constant slope over a satisfactory working range of angular displacements between said windings.
- [Price 3s. 0d.]

According therefore to one aspect of the invention there is provided a variable inductive device, such as a rotatable transformer having two inductively coupled elements respectively carrying the primary winding and the secondary winding, for producing a desired non-sinusoidal relationship between the secondary voltage and the angular displacement between the primary and secondary windings, in which the secondary winding includes a series of coils which lie in slots with the same or a different number of turns and a different slot-pitch for each independent coil, which are all substantially symmetrical about an axis normal to the axis of rotation, and which are distributed to produce a series of predetermined different harmonics of predetermined amplitude in said relationship between the secondary voltage and the angular displacement between the primary and secondary windings.

The preferred embodiments of the invention will now be described by way of example with reference to the accompanying drawings wherein like reference numerals refer to similar parts and wherein:

Fig. 1 illustrates schematically minimum and maximum coupling positions for a rotatable transformer;

Fig. 2 illustrates graphically the sinusoidal relationship between the degree of coupling or voltage output and the angular displacement of the rotor from the stator in a conventional rotatable transformer or variable inductor;

Fig. 3 illustrates graphically the relationship between the degree of coupling or voltage output and the angular displacement of the rotor from the stator provided by one type of linear-output rotatable transformer or variable inductor constructed and wound in accordance with the present invention;

Fig. 4 is a front elevational diagram of a 9-slot stator for a linear-output type rotatable transformer or other rotatable inductive device in accordance with the present invention and showing one type of rotor that may be employed, the stator coils being omitted for simplicity;

Fig. 5 is a front elevational diagram of a 9-slot stator for a linear-output type rotatable transformer or other rotatable inductive device illustrating the position of the four coils wound in accordance with the present

invention; the rotor being omitted for the sake of clearness;

Fig. 6 is a front elevational of a 15-slot stator for a linear-output type rotatable transformer or other rotatable inductive device illustrating the position of the seven coils wound in accordance with the present invention, the rotor being omitted for the sake of clearness; and

Fig. 7 is a detailed side view, partially in section, of a linear-output type rotatable transformer constructed and wound in accordance with the present invention.

In accordance with one aspect of the present invention there is provided a method and means for obtaining in an inductive coupling device a predetermined desired non-sinusoidal relationship between coupling or output voltage and the relative position or angular displacement between the inductively coupled relatively movable elements, the winding of one of the elements being distributed to produce a series of desired different harmonics in said relationship between coupling or output and relative position or displacement. In another more specific aspect an analysis such as a Fourier analysis of the waveform of said desired non-sinusoidal relationship is made to determine the maximum amplitude E_h for each of the component harmonic voltages corresponding to said desired harmonics, and the winding of one of the elements is distributed on a slotted core into a number of substantially parallel, or equivalent, coils wound symmetrically about an axis normal to the axis of displacement or rotation with the distribution determined by the simultaneous solution of a number of equations including a finite series of sinusoidal terms, each of the equations expressing, for a respective coil and for the particular harmonic, the coils coupling or component voltage contribution to the resultant output voltage as dependent upon the number of its turns, the effective position of its conducting bars at any of a number of equally spaced points so that the coils have their bars effectively lumped at electrical angles which are integer multiples of the spacing between said points. For a symmetrical waveform and core having an odd number of slots n the general formula for the equation is:

$$E_h = K_h(N_1 \sin h\theta_1 + N_2 \sin h\theta_2 + N_3 \sin h\theta_3 \dots + N_n \sin h\theta_n) \quad (4)$$

where N is the unknown to be solved and represents the number of turns in a coil having a pitch of the number of slots indicated by the subscript, h is the order of the particular harmonic in the relationship between the degree of coupling or the output voltage and the relative position or angular displacement between the relatively movable elements, K_h is the coupling factor for the h order harmonic and may be determined by one

skilled in the art, and θ is the placement angle, with respect to the axis of the winding, of the coil having a pitch of the number of slots indicated by the subscript, whereby the harmonics and component harmonic voltages of the different orders combine to produce said output voltages and said predetermined non-sinusoidal relationship between said degree of coupling or output voltage and the relative position or angular displacement

between the relatively movable elements.

Turning to Fig. 1 there is illustrated schematically a rotatable transformer 11 having a rotatable primary winding 12 wound on a rotor (not shown) and a stationary secondary winding 13 wound on a stator (not shown). The primary winding is connected across a pair of terminals 14, 15 for energization from an a.c. source (not shown). For purposes of discussion it will be assumed that the magnitude of the input voltage applied to the primary winding remains constant. When the primary winding and rotor are rotated to a null position so that the primary and secondary windings are effectively at right-angles to each other, as shown in Fig. 1(a), so that there is minimum coupling or flux linkages between the primary and secondary, then the a.c. voltage induced in the secondary winding is zero or substantially zero. As shown by the positive half of the wave in Fig. 2, when the rotor of a conventional rotatable transformer is angularly displaced slowly in one direction away from its null or minimum coupling position the degree of coupling between the primary and secondary windings and the secondary voltage correspondingly increase but in a sinusoidal manner.

When the rotor has been angularly displaced 90° from its null or zero-output position so that the primary and secondary windings are effectively parallel to each other, as shown in Fig. 1(b), so that there is maximum coupling or flux linkages, then the a.c. voltage induced in the secondary winding will be maximum. If the rotor is instead rotated in the opposite direction away from such null position, then as shown by the negative half of the wave in Fig. 2 an a.c. voltage of opposite phase will be induced in the secondary winding and will increase in amplitude, again in a sinusoidal manner, until the windings are again effectively parallel with maximum coupling which causes a maximum a.c. voltage of said opposite phase to be induced in the secondary winding. The relationship represented in Fig. 2 also applies for a rotatable transformer where the primary winding is stationary and the secondary winding is wound on the rotor.

As previously indicated the present invention makes it possible to construct a rotatable transformer wherein there is obtained, over a satisfactory range or ranges of angular displacements, a substantially linear relationship relating the coupling or voltage output to the angular displacement between the rotor and the stator, and hence the displacement between the primary and secondary windings. As indicated by the solid curve in Fig. 3, a substantially linear variation of one constant slope is obtained for displacements up to approximately 60° on each side of null or zero. Much of the description that follows will be directed by way of example to how

the present invention may be employed to construct such a linear-output type rotatable transformer. However, it is to be understood that the invention also applies to other apparatus employing relatively movable inductively coupled elements where it is required to obtain a predetermined desired non-sinusoidal relationship relating coupling or output voltage to the relative position or angular displacement between the relatively movable elements, for example special types of synchro or resolver devices or rotatable transformer having more than one primary or secondary winding.

As obtained by a Fourier analysis of the waveform, the equation of the waveform representing any desired non-sinusoidal relationship relating coupling or output voltage to angular displacement between the inductively coupled elements appears in the following general form;

$$e_{\phi} = E_0 + E_1 \sin \phi + E_1 \cos \phi + E_2 \sin 2\phi + E_2 \cos 2\phi + E_3 \sin 3\phi + E_3 \cos 3\phi + E_4 \sin 4\phi + E_4 \cos 4\phi + E_5 \sin 5\phi + E_5 \cos 5\phi + \dots + E_x \sin x\phi + E_x \cos x\phi \quad (1)$$

where e_{ϕ} is the instantaneous amplitude of the resultant output voltage corresponding to each possible angular displacement; E_0 is the magnitude of any d.c. voltage component that may be present; E is the maximum amplitude of each of the various odd and even harmonic voltage components, the order of the particular harmonic being denoted by the particular subscript; ϕ is the coupling angle or more particularly the angular displacement between the inductively coupled elements expressed in degrees; and x is the highest harmonic in the series.

Since the output waveform of the relationship relating coupling or output secondary voltage to angular displacement is symmetrical in all respects, the d.c. component, the even-order harmonics and the cosine terms will cancel out. The equation therefore will reduce to the following form:

$$e_{\phi} = E_1 \sin \phi + E_3 \sin 3\phi + E_5 \sin 5\phi + \dots + E_x \sin x\phi \quad (2)$$

where e_{ϕ} is the instantaneous amplitude of the resultant or output voltage corresponding to each possible angular displacement.

E_1 is the maximum amplitude of the fundamental or first harmonic component voltage. E_3 is the maximum amplitude of the third harmonic component voltage.

E_5 is the maximum amplitude of the fifth harmonic component voltage.

E_x is the maximum amplitude of the x harmonic component voltage.

The equation obtained by a Fourier analysis of a pure triangular waveform such as

the one indicated by fig. 3 but with sharp peaks, as indicated by the dotted lines, rather than flattened peaks as indicated by the solid lines in the vicinity of $+90^\circ$ and -90° , is as follows:

$$e_\phi = K(1 \sin \phi - 0.111 \sin 3\phi + 0.0400 \sin 5\phi - 0.0204 \sin 7\phi + 0.0123 \sin 9\phi - 0.00826 \sin 11\phi + 0.00592 \sin 13\phi + \dots + E_x \sin x\phi) \quad (3)$$

- 10 where K is a constant depending upon the particular value of the maximum amplitude of the fundamental voltage.

After the particular voltage for the maximum amplitude of each of the pertinent harmonics for the particular waveform in question has been determined, by the above Fourier analysis method or by other methods such as a graphical analysis etc., then an equation is established for each harmonic in terms of the number of turns in each coil and the placement angles of the various coils, or coil slot location, with respect to the axis of the stator winding, as indicated by the various angles θ in fig. 5. For illustration a simple synchro type stator is employed. Reference may be had to the previously mentioned patent specifications Nos. 671,632 and 680,503 for more detailed construction to aid in a further understanding of the ramifications of the present invention.

- 30 The general formula for the equation for each harmonic is expressed in the following form:

$$E_h = K_h(N_1 \sin h\theta_1 + N_2 \sin h\theta_2 + N_3 \sin h\theta_3 + \dots + N_n \sin h\theta_n) \quad (4)$$

Where n is the total number of coils of different pitch; N is the unknown to be solved and represents the number of turns in a coil having the pitch of the number of slots indicated by the subscript; h is the order of the particular harmonic; K_h , which is the coupling factor for the h order harmonic, depends upon the mechanical configuration of the rotor and stator and may be determined by one skilled in the art; and θ is the placement angle, with respect to the axis of the stator winding, of the coil having a pitch of the number of slots indicated by the subscript.

- 50 For example, the equations for the first, third, fifth and $(2n-1)$ harmonic take the following form, respectively:

$$E_1 = K_1(N_1 \sin \theta_1 + N_2 \sin \theta_2 + N_3 \sin \theta_3 + \dots + N_n \sin \theta_n) \quad (5)$$

$$E_3 = K_3(N_1 \sin 3\theta_1 + N_2 \sin 3\theta_2 + N_3 \sin 3\theta_3 + \dots + N_n \sin 3\theta_n) \quad (6)$$

$$E_5 = K_5(N_1 \sin 5\theta_1 + N_2 \sin 5\theta_2 + N_3 \sin 5\theta_3 + \dots + N_n \sin 5\theta_n) \quad (7)$$

$$E_{(2n-1)} = K_{(2n-1)} N_1 \sin (2n-1) \theta_1 + N_2 \sin (2n-1) \theta_2 + N_3 \sin (2n-1) \theta_3 + \dots + N_n \sin (2n-1) \theta_n \quad (8)$$

where $E_{(2n-1)}$ = maximum amplitude of the $(2n-1)$ harmonic.

n = total number of coils of different pitch.

K_1 = coupling factor for fundamental or first harmonic.

K_3 = coupling factor for third harmonic.

K_5 = coupling factor for fifth harmonic.

$K_{(2n-1)}$ = coupling factor for $(2n-1)$ harmonic.

N_1 = number of turns in coil of 1-slot pitch.

N_2 = number of turns in coil of 2-slot pitch.

N_3 = number of turns in coil of 3-slot pitch.

N_n = number of turns in coil of n-slot pitch.

θ_1 = placement angle of coil with 1-slot pitch.

θ_2 = placement angle of coil with 2-slot pitch.

θ_3 = placement angle of coil with 3-slot pitch.

θ_n = placement angle of coil with n-slot pitch.

The equations are then solved simultaneously for the values of the only unknowns which are the values of N_1, N_2, N_3, \dots and N_n . It will be apparent from the laws of simultaneous equations that the number of harmonic which are controllable depends upon the total number of coils n of different pitches which are available, which depends upon the total number of slots available.

The maximum number of harmonics which can be controlled by any given winding of the simple cylindrical stator, or rotor, type core is as follows:

$$\frac{n_t - 1}{2} \quad \text{where } n_t \text{ is odd}$$

$$\frac{n_t}{4} \quad \text{where } n_t \text{ is even}$$

where n_t is the number of available slots. The advantage of using a winding having an odd number of slots is obvious from the above. By the above method it is relatively simple to determine the winding for any given output waveform. Any value of N, which is negative requires that the turns for that coil be wound opposite to the normal direction of winding. As stated previously, the coils are all connected in series so that the harmonic component voltages are added algebraically.

In one construction in accordance with the present invention a 15-slot (7 coil) stator was employed to provide a relationship as indicated by the solid line curve in Fig. 3

- with the following values for the ratio of the maximum amplitude of each of the harmonic component voltages E_h to the maximum amplitude of the fundamental component voltage E_1 , the following values of the coupling factor K for the various harmonics, the following values for the number of turns N for each coil of different slot-pitch in the stator winding and the percentage of the total number of turns of the stator winding which the turns of each coil represent:

	Voltage ratio	Coupling Factor	Turns	Percent of Total
15	$\frac{E_1}{E_1} = 1.000$	$K_1 = -1.000$	$N_1 = 165$	15.4
	$\frac{E_3}{E_1} = -0.102$	$K_3 = 0.259$	$N_2 = 155$	14.5
	$\frac{E_5}{E_1} = 0.0232$	$K_5 = -0.0984$	$N_3 = 150$	14.0
20	$\frac{E_7}{E_1} = -0.00742$	$K_7 = 0.0466$	$N_4 = 150$	14.0
	$\frac{E_9}{E_1} = 0.000815$	$K_9 = -0.00772$	$N_5 = 150$	14.0
	$\frac{E_{11}}{E_1} = 0.00105$	$K_{11} = -0.0166$	$N_6 = 150$	14.0
25	$\frac{E_{13}}{E_1} = 0.00229$	$K_{13} = 0.00775$	$N_7 = 150$	14.0

- In another construction in accordance with the present invention a 15-slot (7-coil) stator may be employed to provide a relationship which approaches a pure triangular waveform as indicated by the curve in Fig. 3 but with the dotted sharp peaks with the values for the ratio of the maximum amplitude of each of the harmonic component voltages E_h to the maximum amplitude of the fundamental component voltage E_1 as given by the suffix for each of the seven sinusoidal terms in equation (3) supra and with the following values of the coupling factor for the various harmonics, the following values for the number of turns N for each coil of different slot-pitch in the stator winding and the percentage of the total number of turns of the stator winding which each coil represents:

Coupling Factor	Turns	Percent of Total
$K_1 = -1.000$	391	20.2
$K_3 = 0.259$	259	13.4
$K_5 = -0.0984$	-258	13.4
$K_7 = 0.0466$	495	25.5
$K_9 = -0.00772$	124	6.45
$K_{11} = -0.0166$	-110	5.68
$K_{13} = 0.00775$	299	15.4

- In another construction in accordance with the present invention a 9-slot (4-coil) stator was employed to provide a relationship similar to that indicated by the solid-line curve in Fig. 3. In this construction, indicated in Fig. 5, the coil of 1-slot pitch, the coil of 2-slot

pitch, the coil of 3-slot pitch and the coil of 4-slot pitch were each provided with 260 turns. The primary winding had 380 turns.

Where desired, the following approach may be followed to determine the values of the coupling factor K for each harmonic. It will be assumed that a 9-slot (4 coil) stator is to be used by way of example. Starting with the waveform of the desired relationship between the output voltage and angular displacement, for a given or constant input voltage applied to the primary winding, a Fourier analysis is made as indicated by equations (2) and (3) to obtain the desired values of the maximum amplitudes E_1 , E_3 , E_5 and E_7 of the various harmonic component voltages. A 9-slot stator is then wound with the four coils. Estimated or trial values are used for the number of turns N_1 , N_2 , N_3 and N_4 for each coil. The rotatable transformer is then put together with such trial values for the number of turns in the stator winding, and the primary winding is then connected across the a.c. source. The rotor is turned through angular increments, for example every 2° over a range of 180° and measurements are taken of the secondary output voltage for each increment. A Fourier analysis of the obtained waveform provides tentative values for the maximum amplitudes E_1 , E_3 , E_5 and E_7 of the harmonic component voltages. Tentative equations like equations (5)–(8) supra are then written for said tentative values of E_1 , E_3 , E_5 and E_7 in terms of the placement angles θ_1 , θ_3 , θ_5 and θ_7 and trial values of N_1 , N_2 , N_3 and N_4 . Since the only unknown are the tentative values of the coupling factors K_1 , K_3 , K_5 and K_7 , the tentative equations may be solved for the tentative K values.

A new set of equations like equations (5)–(8) supra is then written for said desired values of E_1 , E_3 , E_5 and E_7 in terms of the placement angles θ_1 , θ_3 , θ_5 and θ_7 , and the tentative values for K_1 , K_3 , K_5 and K_7 . The new set of equations is then solved simultaneously for the tentative values of N_1 , N_2 , N_3 and N_4 . The stator is then rewound with the number of turns for each coil in accordance with said tentative values of N_1 , N_2 , N_3 and N_4 . Measurements of the output voltage are again taken in increments as before. If the waveform obtained is not as close as necessary to the waveform of said desired voltage-displacement relationship, then the procedure is repeated until the desired relationship is obtained.

Fig. 7 shows a detailed construction of a rotatable transformer 24 in accordance with the present invention. Mounted within a housing 26 is a stator assembly 28. The coils of the stator winding 30 are wound in the slots of the stator core 32 as previously described. The rotor assembly 34 includes the two-pole rotor core 36 mounted for rotation on a shaft 38 which is supported in suitable bearings at

the ends of the housing. An insulated electrical cable 42 passes through an end wall of the housing to provide electrical connection with the terminals of the stator winding. An insulated electrical cable 44 passes through the end wall to provide electrical connection with the terminals of the rotor winding by means of the slip-ring and brush construction indicated generally at 46. The upper half 48 and the lower half 50 of the rotor winding are wound on the rotor core as indicated. The rotor winding is illustrated diagrammatically in Fig. 4 and a salient pole rotor is illustrated by way of example. The rotor and stator cores may be laminated as shown with silicon-iron transformer lamination stock. In order to eliminate slot effect the slots of the stator may be provided with a skew equal to the separation distance between the centers of two adjoining slots, that is a skew of one slot pitch.

It is to be understood that the present invention applies equally as well to the construction and winding of a secondary winding on a slotted rotor where the primary winding is wound on two-pole stator core. Although certain forms of the invention have been illustrated and described in detail by way of example, it is to be expressly understood that the invention is not limited. Specific values of voltage ratios, number and percentage of coil turns, coupling factors, placement angles, number of slots, coils and harmonics, etc. have been given simply by way of example. Various changes may be made in the mechanical and electrical design and arrangement of the elements without departing from scope of the appended claims as will now be understood by those skilled in the art.

What we claim is:—

1. A variable inductive device, such as a rotatable transformer having two inductively coupled elements respectively carrying the primary winding and the secondary winding, for producing a desired non-sinusoidal relationship between the secondary voltage and the angular displacement between the primary and secondary windings, in which the secondary winding includes a series of coils which lie in slots with the same or a different number of turns and a different slot-pitch for each independent coil, which are all substantially symmetrical about an axis normal to the axis of rotation, and which are distributed to produce a series of predetermined different harmonics of predetermined amplitude in said relationship between the secondary voltage and the angular displacement between the primary and secondary windings.

2. A variable inductive device, such as a rotatable transformer, for producing a substantially linear relationship between the secondary voltage and the angular displacement between the primary and secondary windings, comprising a rotor and a stator

element, one of said elements including an electromagnetically bisymmetrical bipole carrying the primary winding which is connectable to a source of periodically varying electrical energy, and the other of said elements carrying a secondary winding formed of a number of independent substantially parallel coils wound symmetrically about an axis normal to the axis of rotation and interconnected to produce component harmonic voltages of predetermined magnitudes which algebraically add to produce a resultant voltage which is said secondary voltage and which are, respectively, predetermined desired harmonics in the relationship between said secondary voltage and the angular displacement between said primary and secondary windings.

3. A variable inductive device as claimed in claim 1 or 2 in which the element carrying the secondary winding has a 15-slot core and the secondary winding distributed thereon comprises parallel, or equivalent, coils with the turns in each coil having approximately the following respective percentage of the total number of turns in the winding:

	coil, slot pitch	turns, per cent of total
30	1	15.4
	2	14.5
	3	14.0
	4	14.0
	5	14.0
35	6	14.0
	7	14.0

4. A variable inductive device as claimed in claim 1 or 2, in which the element carrying the secondary winding has a 15-slot core and the secondary winding distributed thereon comprises parallel, or equivalent, coils with the turns in each coil having approximately the following respective percentage of the total number of turns in the winding:

coil, slot pitch	turns, per cent of total
1	20.2
2	13.4
3	13.4
4	25.5
5	6.45
6	5.68
7	15.4

5. A variable inductive device as claimed in claim 1 or 2, in which the element carrying the secondary winding has a 9-slot core and the secondary winding distributed thereon comprises parallel, or equivalent, coils with the turns in each coil having approximately the following respective percentage of the total number of turns in the winding:

coil, slot pitch	turns, per cent of total
1	25
2	25
3	25
4	25

6. A variable inductive device as claimed in claim 3, 4 or 5, in which the slots of the core of the element carrying the secondary winding have a one-slot skew to eliminate slot effect.

7. A variable inductive device constructed and adapted to operate substantially as described with reference to the accompanying drawings.

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Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press.—1957.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which
copies may be obtained.

FIG. 2

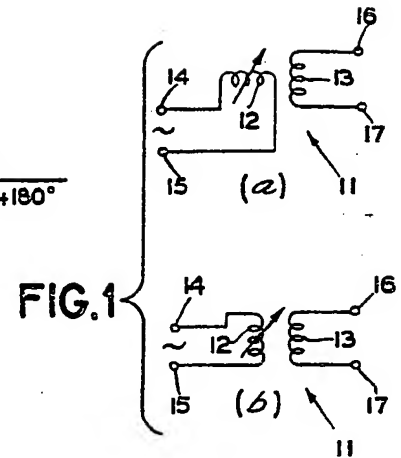
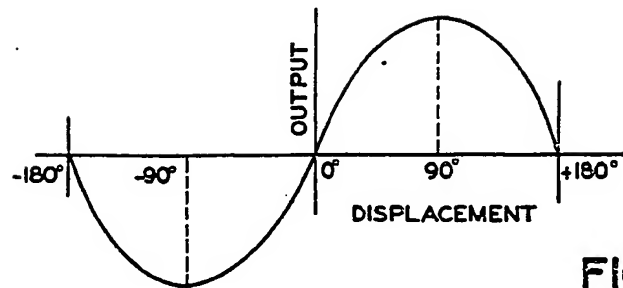


FIG. 3

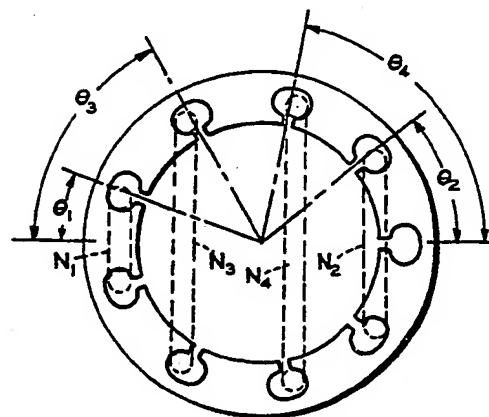
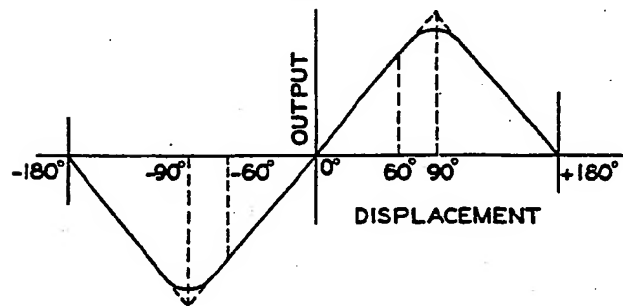
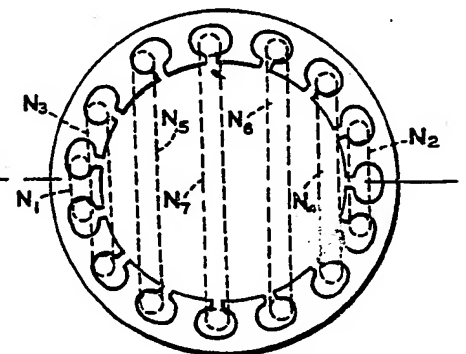


FIG. 5

FIG. 6



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FIG. 4

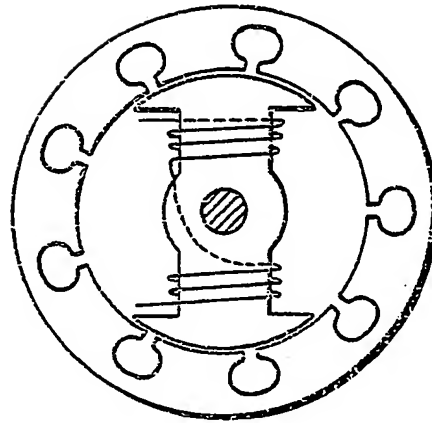
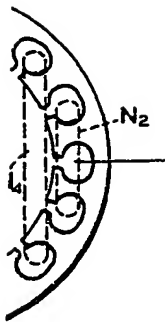
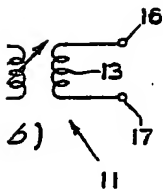
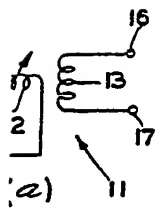
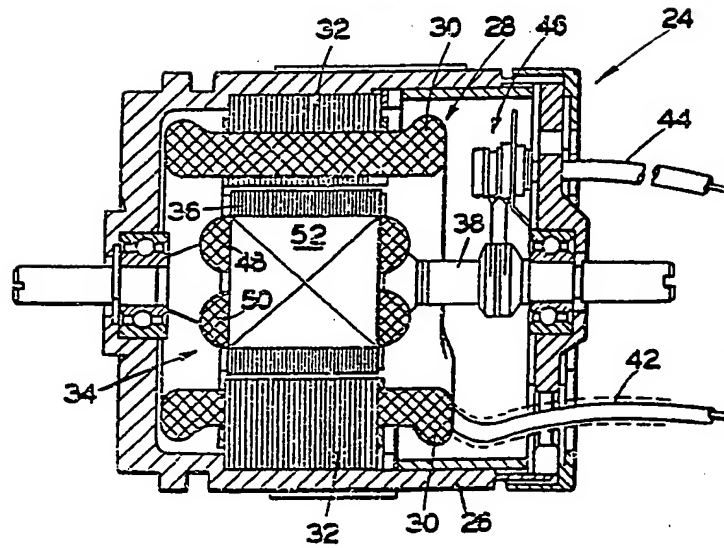


FIG. 7



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 Sheet 1 of 2

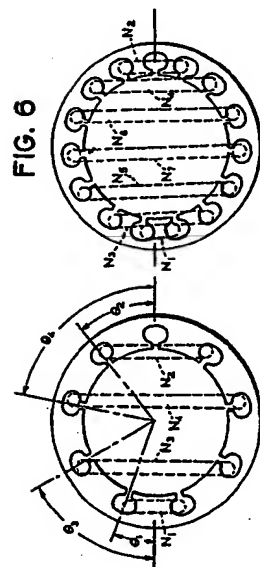
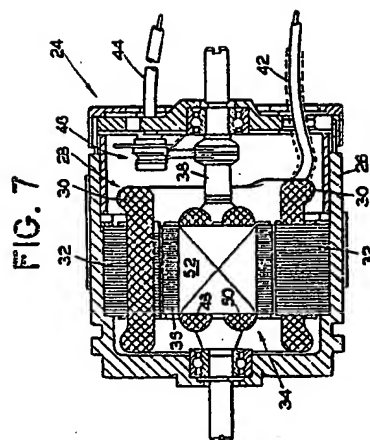
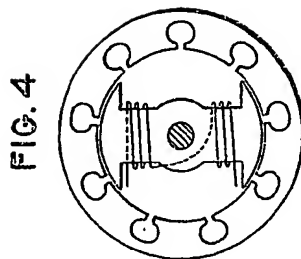
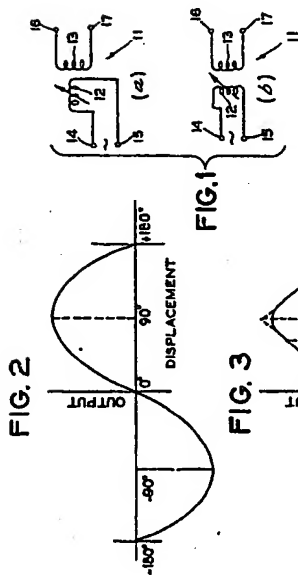


FIG. 5